THE EFFECT OF RECYCLED –POLYCARBONATE (PC) MIXING RATIO ON THE TENSILE STRENGTH OF POLYCARBONATE POLYMER

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ABSTRACT

Nowadays, plastic and metal are used as raw material at the industries for their product. Plastic can be divided into two types which are thermoset and thermoplastic. Thermoplastic usually used compare to thermoset because it can be recycled and molded to be manufactured as a new product. Polycarbonate is an example of thermoplastic that widely used in the industries. Polycarbonates are condensation polymers with many desirable properties. They exhibit very high thermal stability and have a high heat distortion temperature. The problem happened when there are many wastes of products made from polycarbonate. The objective of this study is to investigate the effect of recycled Polycarbonate mixing ratio on the tensile strength of Polycarbonate polymer. Therefore, the mold was designed to produce tensile bar as a specimen to achieve the objective. Polycarbonate was dried at temperature 80°C for 4 hours by using vacuum oven and then the materials was injected using the injection molding machine. Then, the product produced was used as recycled material and mixed with virgin polycarbonate with different percentages. There are five samples of recycled PC/virgin PC percentages: 0/100, 25/75, 50/50, 75/25 and 100/0 respectively. The mixed material was injected to produce the specimen. The specimens of each experiment was tested by using Universal Tensile Machine to determine the best percentage mixing of the recycled Polycarbonate with the virgin Polycarbonate that has highest tensile strength. From the result, the testing part showed the highest tensile stress at maximum load is 0% recycled of polycarbonate which is 54.22611 MPa. The second highest is Experiment 4 that has 75% recycled polycarbonate, which is 52.77886 MPa. In addition, the lowest tensile stress at maximum load is 25% recycled polycarbonate, which is 49.17192 MPa. Thus, the properties of specimen in experiment 1 have good properties such as high strength and excellent toughness compared to another. The higher tensile stress also shows that the material is more brittle and less ductile.

ABSTRAK

Pada masa kini, plastik dan logam telah digunakan sebagai bahan mentah di industri untuk produk mereka. Plastik boleh dibahagikan kepada dua jenis iaitu thermoset dan termoplastik. Termoplastik biasanya digunakan berbanding dengan thermoset kerana ia boleh dikitar semula dan dibentuk menjadi produk baru. Polikarbonat adalah contoh termoplastik yang digunakan secara meluas dalam industry. Polikarbonat adalah polimer pemeluwapan dengan banyak ciri-ciri yang diingini. Mereka mempamerkan kestabilan terma yang sangat tinggi dan mempunyai haba yang tinggi suhu penyelewengan. Masalah berlaku apabila terdapat banyak sisa produk polikarbonat. Objektif kajian ini adalah untuk mengkaji kesan kitar semula nisbah pencampuran polikarbonat pada kekuatan tegangan polimer polikarbonat. Oleh itu, acuan telah direka untuk menghasilkan bar tegangan sebagai specimen untuk mencapai matlamat ini. Polikarbonat telah dikeringkan pada suhu 80°C selama 4 jam dengan menggunakan oven vakum dan kemudian bahan-bahan tersebut disuntik dengan menggunakan mesin pengacuan suntikan. Kemudian, produk yang dihasilkan telah digunakan sebagai bahan kitar semula dan di campur dengan polikarbonat asli dengan peratusan yang berbeza. Terdapat lima sampel peratusan bagi campuran kitar semula PC / asli PC, masing-masing adalah 0/100, 25/75, 50/50, 75/25 dan 100/0. Bahan campuran telah disuntik untuk menghasilkan spesimen. Spesimen setiap eksperimen telah diuji dengan menggunakan mesin tegangan universal untuk menentukan peratusan yang terbaik bagi campuran Polikarbonat kitar semula dengan polikarbonat asli yang mempunyai kekuatan tegangan yang tinggi. Dari hasil kajian, bahan ujian yang menunjukkan tengangan yang tertinggi pada beban maksimum ialah 0% daripada polikarbonat dikitar semula, iaitu 54.23 MPa. Untuk yang kedua tertinggi ialah pada Eksperimen 4 yang mempunyai 75% polikarbonat yang dikitar semula iaitu 52.78 MPa. Di samping itu, tegangan paling rendah pada beban maksimum adalah 25% polikarbonat yang di kitar semula, adalah 49.17 MPa. Oleh itu, sifat-sifat spesimen dalam eksperimen 1 mempunyai ciri-ciri yang baik seperti kekuatan yang tinggi dan ketahanan yang sangat baik berbanding dengan yang lain. Tegasan tegangan yang lebih tinggi juga menunjukkan bahawa bahan ini adalah lebih rapuh dan kurang mulur.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Nowadays, plastic and metal are used as raw material at the industries for their product. Around 1909, the word plastics first used as a noun and commonly is employed as a synonym for polymers. Plastic can be divided into two types which are thermoset and thermoplastic. Thermoplastic is usually used compare to thermoset because it can be recycled and molded to be manufactured as a new product.

The example of thermoplastic that commonly used is Polycarbonate (PC). Polycarbonate is produced by reaction of bisphenol-A and phosgene ($COCL_2$) [1]. Polycarbonate can be found in many applications because it has good properties such as high strength that make it resist to impact and fracture. It also has high transparency and high heat resistance. The melting point of polycarbonate is approximately 149°C or 300°F. The minimum and maximum temperature of polycarbonate is 121°C and -40°C respectively. The tensile strength of polycarbonate is 63 MPa and its flexural strength is 89 MPa. These mechanical properties make polycarbonate found in many applications. They have good mechanical and electrical properties, high impact resistance, and they can be made resistant to chemicals [2]. The refraction of transparent and colorless index of polycarbonate is very high which is 1.584 [3].

Therefore, as widely used in many applications, the goods made from polycarbonate cause waste that harmful the environment and ecosystems. This happen

because as a plastic, polycarbonate take a long time to dispose. Then, to solve this problem, the product that made from polycarbonate can be recycled and reused to manufacture as a new product. In this project, dog bone shape will be produced as part to be recycled. In this study, we will investigate the effect of recycled polycarbonate mixing ratio on the tensile strength of polycarbonate polymer. The virgin polycarbonate polymer in the pellet form will mixed with recycled polycarbonate to know which composition will produce best result of the tensile strength of polycarbonate.

1.2 PROBLEM STATEMENT

The polycarbonate plastic was used widely because of its properties that high transparency, lightweight, easy to shape, high strength and so on. The problems arise when the polycarbonate plastic become a waste after it was used. The alternative ways such as recycle and reuse the polycarbonate product is used to reduce the waste. However, by recycling and reuse the polycarbonate product, we do not know how the recycling polycarbonate affects the tensile strength of polycarbonate polymer, either this properties of polycarbonate become greater or not. In addition, there is not much research has been done on recycled polycarbonate and the effect on the tensile strength. Typically, studies have been done on the effect of two types of recyclable materials such as polycarbonate with Acrylonitrile butadiene styrene (ABS)

Therefore, a study is needed to investigate the effect of recycled polycarbonate on the mechanical properties of polycarbonate polymer which is tensile strength. The purpose of this study is to investigate either the tensile strength of recycled polycarbonate is higher or lower than the product made from pure polycarbonate. In this project, the recycled polycarbonate will mix with the virgin polycarbonate and testing its tensile strength.

1.3 OBJECTIVE OF THE PROJECT

1. To design the mold to produce the dog bone shape as a specimen that will be used in this study.
2. To investigate the effect of recycled Polycarbonate mixing ratio on the tensile strength of Polycarbonate polymer.
3. To determine the best percentage mixing of the recycled Polycarbonate with the virgin Polycarbonate that has highest tensile strength.

1.4 SCOPE OF THE PROJECT

This project will use the recycled Polycarbonate that mixed with virgin Polycarbonate. The recycled Polycarbonate will be mixed with virgin Polycarbonate according to several percentages. The specimens of each experiment will be tested for their tensile strength by using Universal Tensile Machine. The tensile test will follow the American Society for Testing and Materials (ASTM) D638 standard to get the result. The research will be done at the laboratory of Faculty of Manufacturing Engineering.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In our everyday lives we are surrounded by a seemingly endless range of polymers. A polymer is a large molecule composed of repeating structural units or chain typically connected by covalent chemical bonds. Consumer and industrial products made of polymers include food and beverage containers, packaging, signs, housewares, housing for computers and monitors, textiles, medical devices, foams, paints, safety shields, toys, appliances, lenses, gears, electronics and electrical products and automobile bodies and components.

The unique and diverse properties of polymers have replaced the metallic components in many applications such as automobile, civilian and military aircraft, sporting goods, toys, appliances, and office equipment. The properties of polymers depend largely on the structures of individual polymer molecules, molecule shape and size, and how molecules are arranged to form a polymers structure [4]. Many applications of component from polymer lead to the waste. The percentages of waste increase day by day as the component make from polymer are not easy to dispose.

In this chapter, it will discuss about the research that have been done to avoid the wastes from polymer. There are several alternative ways such as recycled the waste to manufacture as a new product. A review of other relevant research studies is also provided in this chapter.

2.2 POLYCARBONATE (PC)

Polycarbonate is an example of thermoplastic that widely used in the industries. Thermoplastic is a polymer that becomes moldable above a specific temperature and returns to a solid state upon cooling [5]. Thermoplastic polymer can be repeatedly softened by heating, molded to a new shape and then cooled to harden it. The thermoplastic will become leathery when its temperature is raised above its glass-transition temperature and then becomes rubbery with increasing temperature [6]. The thermal and electrical properties of plastics generally lower compared to metal [7]. Therefor, they are used as an insulator and as packaging material for electronic components.

Polycarbonates are condensation polymers with many desirable properties. They exhibit very high thermal stability, have a high heat distortion temperature and, despite their hardness, display ductile rather than brittle failure on impact, making them very tough [9]. Polycarbonates have high clarity and process easily on standard extrusion, injection and blow molding equipment [9]. Polycarbonate is produced from the condensation reaction between bisphenol A and a difunctional, proton-accepting species such as diphenyl carbonate or phosgene [9].

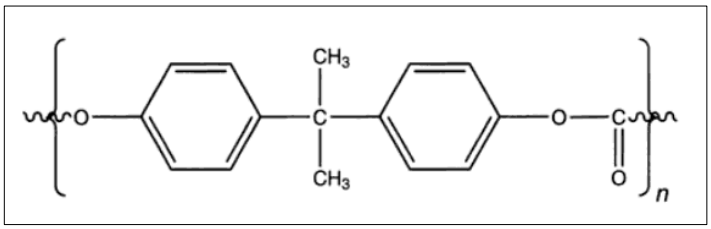

Figure 2.1: Chemical structure of bisphenol A based polycarbonate [9]

In addition, bisphenol A or official chemical name is 2,2-bis(4-hydroxyphenyl) propene, is a difunctional monomer with two reactive hydroxyl groups. Then, it polymerizes with dicarbonyl organic monomers such as phosgene or diphenyl carbonate

[9]. The hydroxyl groups of the bisphenol A deprotonate in the presence of a base during the polymerization [9]. Then, the oxygen atoms on the bisphenol A residue form ester bond with the dicarbonyl compounds after deprotonation [9]. The polymerization process terminates when a monohydric phenol reacts with the growing chain end [9].

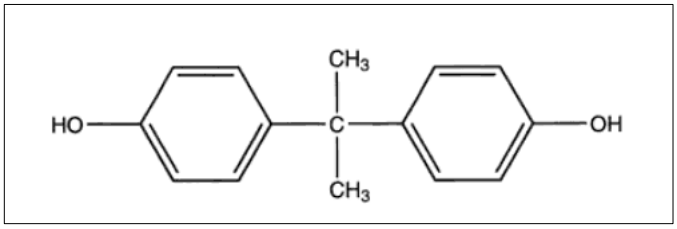

Figure 2.2: Chemical structure of bisphenol A [9]

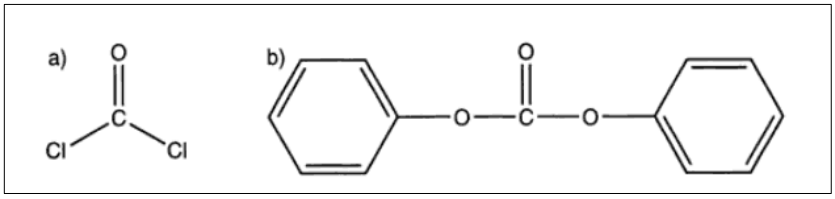

Figure 2.3: Chemical structure of (a) Phosgene (b) Diphenyl carbonate [9]

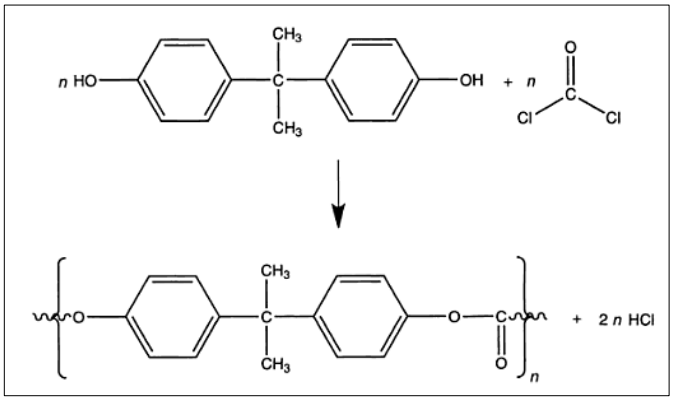

Figure 2.4: Polymerization of polycarbonate from bisphenol A and phosgene [9]

2.2.1 PROPERTIES OF POLYCARBONATE

The properties of polycarbonate such as excellent toughness, transparency, thermal stability and very good dimensional stability make it one of the most widely used engineering thermoplastics. Polycarbonate is an amorphous engineering material that offers clarity, excellent toughness and ductability over a wide temperature range. These properties coupled with good creep resistance, dimensional stability, and electrical insulating characteristics have made polycarbonate one of the most used plastic materials [10]. Polycarbonate has excellent transparency when uncrystallized and when it thick, it has a slight yellowish tint [3]. Besides, polycarbonates are strong, stiff, hard, tough engineering thermoplastics that can maintain rigidity up to 140 ^{o}C and toughness down to -20 ^{o}C [11]. In addition, polycarbonate has low scratch-resistance although it has high impact-resistance.

Besides having high transparency, polycarbonate also offers characteristics such as high strength that making polycarbonate resistant to impact and fracture. It also has high heat resistance that making it ideal for application that requires sterilization. In addition, by having good electrical insulation properties, polycarbonate was used in electric kettles, fridges, food mixers, electrical shavers, hairdryers, and so on. In addition, polycarbonate also used in the automotive field. The example component in automotive that used polycarbonate are tail lights, turn signals, back-up lights, fog lights and headlamps. Polycarbonate also used in electrical and electronics application because of its light weight and impact and shatter resistant qualities make it perfect for housing cell phones, computers, fax machines, and so on [12].

Before polycarbonate transformed into the required shape or product, it need to melt and then forcing under pressure into a mold or die. There are two dominant processes involved in making product from polycarbonate. The processes are extrusion and injection molding [12]. In this study, the process use for polycarbonate is injection molding process. The injection molding process start with the polymers in the form of pellets or granules are fed into the heated cylinder, and the melt is forced into the mold

either by a hydraulic plunger or by the rotating screw system of an extruder [13]. The operation of the injection molding is shown in Figure 2.8.

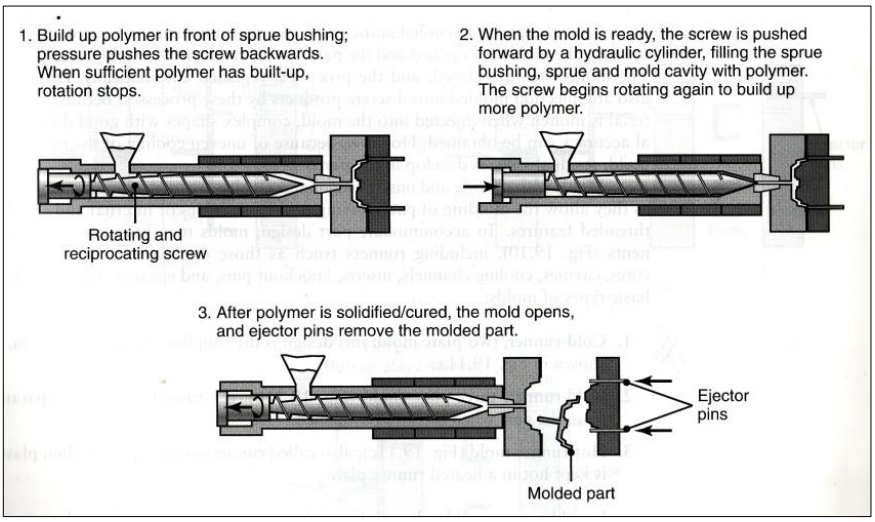

Figure 2.5: Sequence of operations in the injection molding of a part with a reciprocating screw. This process is used widely for numerous consumer and commercial products, such as toys, containers, knobs, and electrical equipment [13].

2.3 PLASTIC RECYCLING

Plastic products had used widely and become common materials of our lives. Their properties, such as light-weight, easy to shape and durability can be a significant factor in achieving sustainable development. Plastic has used in many applications such in automotive, medical equipment, electrical and electronic and many more. This situation contributes to plastic waste that will affect our environment. There are ways to prevent the solid plastic waste become worst to our environment. The solution that used nowadays to reduce plastic waste is recycling process. Plastic can be divided into two categories, thermoplastic and thermoset. The plastic product from thermoplastic can be recycled but thermoset can not be recycled due to its properties.

Thermoplastic product can be recycled because it can be resoftened or remelted and then remolded into a shape a number of times to produce new product. This properties make the product from thermoplastic can be recycled to produce new product and then can reduce plastic waste. There are several advantages of recycling process of plastic waste. First, by recycling the plastic waste, we can reduce oil consumption. The manufacturer plastics from crude oil derivatives or natural gas, so making more plastic consumes an increasing amount on nonrenewable fossil fuel. Besides, recycling the plastic waste can save the energy. The manufacturers must chemically alter crude oil derivatives to produce plastic. This technique consumes a considerable amount of energy. Although the recycling process still uses energy to clean, melt and remold, it usually requires less energy than making plastic from crude oil [14].

Some studies have been done to study the properties such as mechanical properties of recycled materials. Referring to Domingo, there are three main points to evaluate the quality of recycled materials, which are the decomposition, the state of the degradation and the level of contaminants such as additives, fillers and others [15]. According to Callister, any material used in some final product that has not been discarded will pass throughout its life by various stages of use called life cycle of materials [16]. The life cycle of materials shows that the recycling stage comes after the product application and not in previous phases, for example, in the design and manufacture of the product [16].

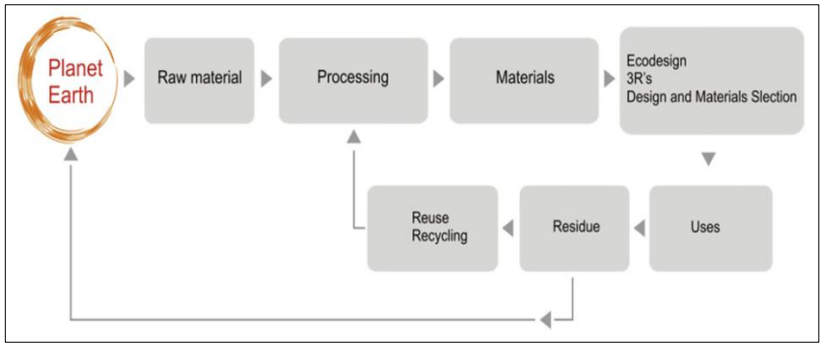

Figure 2.6: Life Cycle of Material [16]

2.3.1 Recycling of Polycarbonate

Polycarbonate (PC) can generally be divided in two chemical categories. They are straight chain or aliphatic, which are not used as thermoplastics and aromatics, which are useful engineering [17]. The most widely used is the most common aromatic polycarbonate, poly(bisphenol A carbonate) [18]. It is widely used in optical data storage such as bulletproof windows, food packing, mineral water bottles, CD, CD-R and DVD discs [19, 20]. In addition, polycarbonate is used in a wide range of industrial applications such as automotive, building, construction and so on because of a series of properties such as excellent thermal and flame resistance, high impact strength and high stability to different environmental conditions [18, 21, 22].

The polycarbonate capacities of the global markets, including North America, South America, Europe and Asia were increased from 1.5 metric tonne (Mt) in 1999 to 1.7 Mt in 2001 [21]. The wastes from widely used of polycarbonate can be recycled for environmental and economics benefits. Polycarbonate recycling can be performed in three main different ways, which are direct recycling, recycling via chemical methods and thermochemical recycling, also called as pyrolysis [18]. The direct recycling also known as mechanical recycling. It also can be blending with other materials. The polycarbonate produced after mechanical recycling exhibits a series of deteriorate properties such as decreased impact resistance when compared to the parent polycarbonate polymer [18]. This problem can be solved by blending with other materials to modify impact resistance [23]. The example of research that have been done on the recycling of polycarbonate is the recycling of poly (ethylene terephthalate) (PET) with polycarbonate blend [24]. This research was conducted by preparing various of composition of PET and polycarbonate blends which are 80/20, 70/30 and 50/50 of PET/PC blends. The purposes of this study are to study the mechanical properties, thermal properties and so on.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will cover the experiment that will be done for this research to get the result. In the methodology process, it consists of several stages. Figure 3.1 shows the flow chart of the project. The project was started with preparation of recycled of polycarbonate. During this stage, polycarbonate will be injected into the injection molding machine to produce a product. After several processes, the samples were undergoing sample testing process. The samples will undergo the Tensile Test. The Tensile Test was referring to ASTM D638 standard. The project was concluded by comparing the data from the result of the experiment.

3.1.1 Raw Material

In this project, the raw material that has been selected is polycarbonate (PC). Polycarbonate has been widely used in the industries. The polycarbonate used in this experiment is a product of Samsung Cheil Industries Inc. In addition, polycarbonate has good mechanical properties, high impact resistance, resistance to creep and they can be made resistant to chemical.

Details information of the raw material used in this study are listed below:

- Supplier: SAMSUNG CHEIL INDUSTRIES INC
- Product: INFINO POLYCARBONATE
- Grade: SC-1100UR
- Appearance: Transparent particles
- Package: 25 Kg/Bag
- Origin: Korea

Below is the list of Polycarbonate properties:

- Minimum temperature : 250^{o}F (121^{o}C)
- Maximum temperature : -40^{o}F (-40^{o}C)
- Melting point : 300^{o}F (149^{o}C)
- Tensile strength : 63 MPa
- Flexural strength : 89 MPa

Figure 3.1: Polycarbonate materials

3.1.2 Flowchart

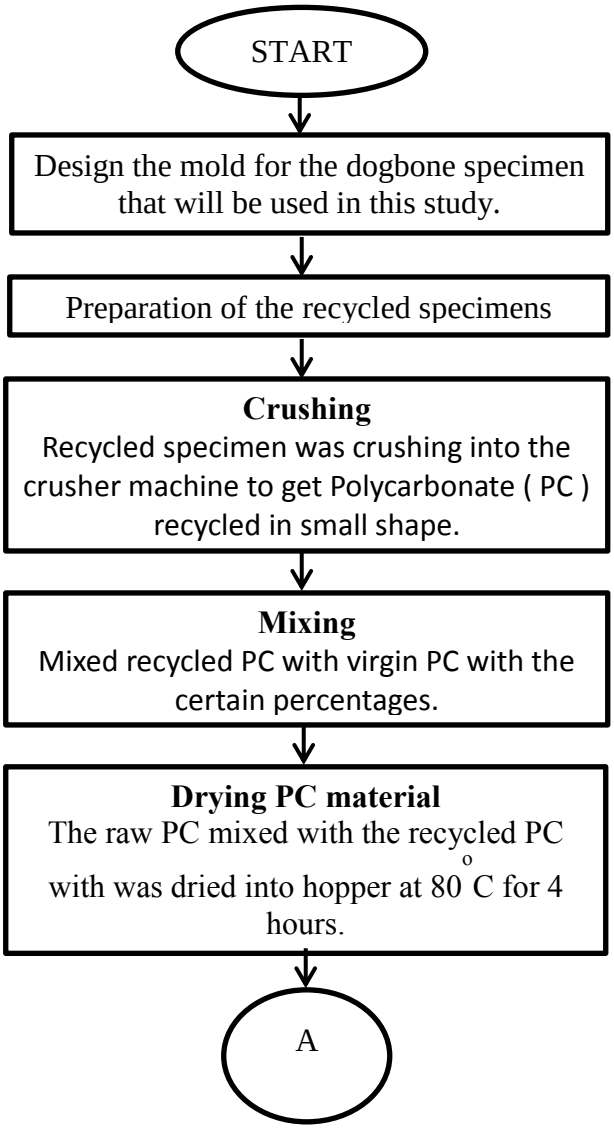

Figure 3.2 (a): Flowchart

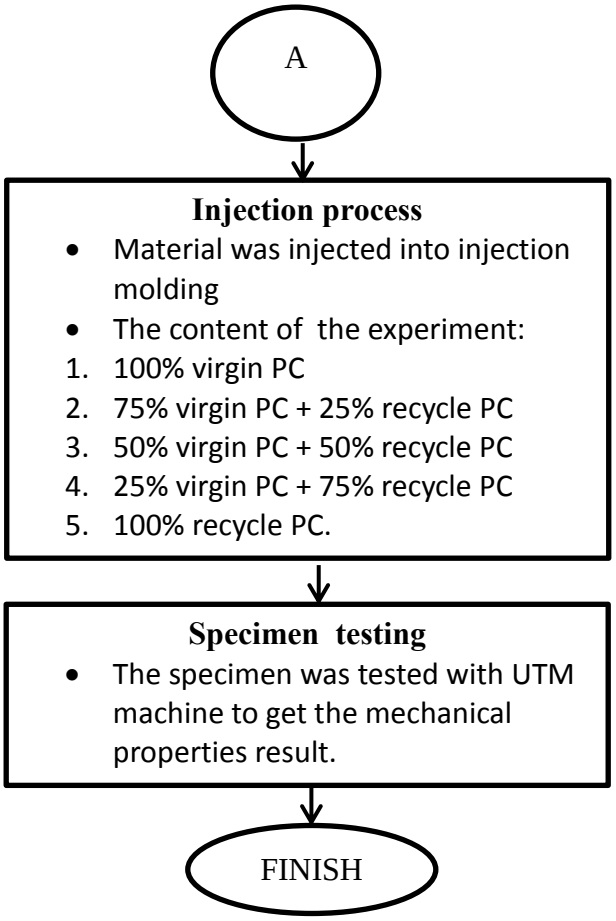

Figure 3.2 (b): Flowchart

3.2 EXPERIMENTAL DESIGN

In order to achieve the result of the experiment, there are many types of method in planning, conducting the experiment and analyzing the data. In this project, we need to mix the recycled and virgin Polycarbonate using different percentage for each experiment. The repetitive method is use for this experiment to get the average result. There are five samples will taken from each experiment. In addition, the sample testing followed the ASTM D638 standard followed by testing by using the Universal testing Machine (UTM). Below is the list of experiment that will be done.

i. Experiment 1 : Content 0% recycled Polycarbonate
ii. Experiment 2 : Content 25% recycled / 75% virgin Polycarbonate
iii. Experiment 3 : Content 50% recycled / 50% virgin Polycarbonate
iv. Experiment 4 : Content 75% recycled / 25% virgin Polycarbonate
v. Experiment 5 : Content 100% recycled Polycarbonate

3.3 MOLD DESIGN

In this experiment, before the material preparation, the mold was designed to produce the dogbone shape that will be used as specimens in this study. The dimension of the dogbone follows the standard of ASTM D638. For rigid or semi rigid plastics, ASTM D638 are preferred specimen and shall be used when sufficient material having a thickness of 7mm or less is available. The dimension of dogbone shape as specimen as below:

- Overall length : 165mm
- Width : 12.7mm
- Thickness : 3.2mm
- Fillet radius : 76mm
- Length of parallel narrow section : 57mm

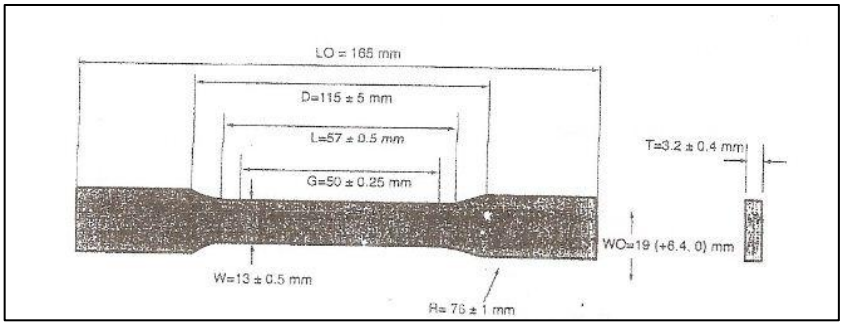

Figure 3.3: Dimension of tensile bar

The software used to draw the mold design is Autodesk Autocad. The drawing of the mold can refer to Appendix A. The mold plates that need to be machined are cavity plate, core plate and ejector plate. The mold plates were machined by using 3-Axis Makino KE55 CNC Milling Machine. The mold was used in injection molding machine to produce the specimens that will be used in this study. The plates were machined by using milling machine. The dogbone shape on the plate was machine by using the EDM Die Sinking machine. The copper electrode that used in die sinking process was cut by using EDM Wire Cut machine to get the dogbone shape.

Figure 3.4: Dogbone electrode

Figure 3.5: Mold plate

Figure 3.6: EDM Die Sinking Machine

Figure 3.7: 3-Axis Makino KE55 CNC Milling Machine

3.4 MATERIAL PREPARATION

In this experiment, the first step is the virgin polycarbonate was injected into the injection molding machine to produce products that will be used as specimens. The product that produced by using injection molding process is a dogbone shape, also known as tensile bar. The product with hundred percent of virgin polycarbonate will take as a sample for first experiment. The specimens were used as recycle material. These products were undergoing several processes until it was inject into injection molding to get the specimens for all experiments.

3.4.1 Crushing

The recycle products that selected from product were crushed into the crushing machine. The purpose of crushing process is to get the recycled product in pellet form that to be used in injection molding process. Then, after crushing process, the recycled material in pellet form was mixed with virgin polycarbonate.